to be established for other varieties that have delayed maturity because of excess acidity.

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TOLERANCE OF TRIFOLIATE ORANGE SELECTIONS AND HYBRIDS TO FREEZES AND FLOODING

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Abstract. **Freezes and floods in Louisiana, freezes in Georgia, and controlled-environment studies in Florida indicate seven selections of trifoliate orange (Poncirus trifoliate [L.] Raf.), a citradia (C. aurantium L. X P. trifoliata), and a citrumelo (C. paradisi Macf. X P. trifoliata) are sources of relatively high tolerance of freezes and flooding. The highest yield of fruit/tree after adverse conditions was not always directly associated with the tolerance of freezes and flooding.**

The effects of adverse environment on citrus trees sometimes can be lessened by appropriate rootstocks (1, 3, 5, 8). In continuing studies of cultivar evaluations, we tested citrus rootstock selections as budded and unbudded trees in the field and as unbudded plants in controlled environments. Results of controlled-environment tests with young plants do not apply equally to mature trees in the field; but the relative ratings of the cultivars tend to be similar between field and controlled-environment tests, even with unbudded young trees (14). In this study, the objectives were to test the reaction of citrus-breeding selections to severe freezing and flooding and to identify potential citrus-breeding material with cold-hardiness and flooding tolerance.

Materials and Methods

Selections of trifoliate orange (*Poncirus trifoliata* [L.] Raf.), trifoliate orange hybrids, and mandarins (*Citrus reticulata* Blanco) were used in this study. Hybrids included citranges (*C. sinensis* [L.] Osbeck X *P. trifoliata*), citrumelo (*C. paradisi* Mac. X *P. trifolata*), citradia CPB 50097 (*C. aurantium* L. X *P. trifoliata*), citrandarin (*P. trifoliata* X *C. reticulata*), citrangedin (citrange X Calamondin [*C. reticulata* var. *austera* X *Fortunella* sp.], and *citrangor* ([C. *sinensis* X *P. trifoliata*] X *C. sinensis*). Plants were from open-pollinated seed, germinated in a glasshouse. One- to 1 1/2-year-old plants were transplanted to the field and used in controlled-environment tests.

Field plantings were near Port Sulphur, Louisiana, and Byron, Georgia. These sites were selected because they may have moderate to severe freezes and/or floods. Rootstocks were tested as scion-rootstock combinations in Louisiana, primarily as unbudded plants in Georgia, and as unbudded plants in controlled-environment tests in Florida. In Louisiana, budded tops were 'Owari' satsuma mandarin (*C. reticulata*) and Washington' navel orange (*C. sinensis.*) Buds were from validated sources. Test trees were randomized in blocks replicated 6 to 8 times, with three single-tree replications per scion-rootstock combination. In Georgia, unbudded rootstocks of 65 to 200 plants each were transplanted 2 ft apart in rows 20 ft apart.

Temperatures in the field were recorded with hygrothermographs in standard weather shelters. Water above ground level was considered as flooding. In Louisiana, tree tolerance of adverse conditions was rated by tree survival counts 1 to 6 months after freezing or flooding. Also, annual crop yields of surviving trees were determined for 5 consecutive years immediately after adverse weather conditions. In Georgia, survival counts were made annually in April and October for 3 years after unbudded rootstocks were planted. Some of the rootstocks included in field trials were also included in controlled-environment tests.

Controlled-environment tests involved plants potted in 3-liter cans filled with a mixture of 1 part sand, 2 parts vermiculite, 7 parts peat, and a trace of mixed fertilizers. Tests were made on 1- to 1 1/2-year-old uniform plants in groups of 30 to 60 single-plant replicates. One-half of the group was selected for cold-hardiness conditioning, and the remaining half of the group was retained as glasshouse (unconditioned) controls.

Conditioning was either slight or moderate in controlled environment rooms 9 ft X 9 ft X 6 ft. Slight hardening off, such as might occur naturally in central Florida, consisted of 70°F (21.1°C), 12-hr days and 50°F (10°C) nights for 2 consecutive weeks. Moderate hardening off, similar to southern California conditions, consisted of slight hardening followed by 2 consecutive weeks of 60°F (15.6°C) days and 40°F (4.4°C) nights. Light, both incandescent and fluorescent, was about 2,000 ft-c at the top of the plants. Temperatures were controllable ± 1°F (0.6°C), relative humidity (RH) was maintained at 60%, and air movement averaged about 3/4 mph.

Controlled freeze tests included glasshouse (nonconditioned) and conditioned plants simultaneously. After treatments, plants were transferred to an adjacent controlled freeze room preset at 35°F (1.7°C) and 50% RH. After 1 hr at 35° F, the temperature was decreased 2°/hr to 20°F. (-6.7°C) for 4 hr and then returned to

Table 1. Field survival of unbudded citrus trees[y] after 3 consecutive winters in Georgia with respective low temperatures of 16°, 3°, and 18° F (-8.9°, -16.1°, and -7.8° C, respectively)

Rootstock selections	Trees planted	Survival
	(No.)	(%)
Trifoliate orange[z]	2,775	100
Citradia CPB 50097	88	67
Citrumello 4475	80	54
Citrumello 4551	112	27
Yuma citrange	132	19
(Temple X trifoliata)	48	12
Changsha mandarin	65	5
Shekwasha mandarin	202	1
Cleopatra mandarin	152	0

[y]Trees were 1 year old at time of first winter.
[z]75 plants of each of 37 different selections.

35° at 2°/hr. After 3 hr of gradual thawing, plants were placed in a glasshouse. Four weeks later, foliage kill and stem dieback were rated.

Results and Discussion

Selections of citrus rootstocks differed in tolerance to test conditions. This was apparent with both unbudded and budded trees exposed to freezing and flooding in the field and with unbudded potted seedlings in controlled conditioning and freezing. The selected rootstocks did not show marked differences in cold tolerance without hardening-off treatments before the controlled freezes. Also, temperatures as low as 3°F (—16.1°C) did not separate selections of *P. Trifoliata* in Georgia, where 100% survived with little or no injury (Table 1). The same selections were uninjured by a 16°F (—8.9°C) freeze in Texas in 1962 (12). Trifoliate orange selections, however, can be separated on the basis of vigor in Georgia and Florida (11).

Trifoliate orange rootstocks of 'Owari' satsuma trees exposed to 14°F (-10°C) and 20°F (-6.7°C) in Louisiana showed differences in tree survival (Table 2). Only trees on selection Rich 22-2 had 100% survival 1 month after the freezes. This selection is vigorous in Florida (11). *P. trifoliata* selections, of which more than 75% survived freezes in Louisiana, included 'English small', 'English large', 'Towne F', and 'Rubidoux 56-6'. 'Towne G' and 'Chambers large' were the only selections that had more than 50% of the trees killed.

Differences in number of trees killed were apparent among citranges as rootstocks of satsuma trees in Louisiana. Seventy-five percent of the trees on 'Uvalda' citrange rootstock survived, as did 50% on 'Carrizo', 'Morton', and 'Troyer', and 33% on 'Rusk' (Table 2). During the 1962 freeze in Texas, all of the 4 year-old 'Valencia' orange (*C. sinensis*) and 'Redblush' grapefruit (*C. paradisi*) trees on 'Morton' citrange survived; whereas only 40 to 50% of the trees survived on 'Carrizo' and 'Troyer' rootstocks (13). 'Uvalde' citrange, which had 75% of its trees surviving freezes in Louisiana, had 100% survival during the 1951 freeze in Texas (2).

In contrast to 'Uvalde', only 58% of the trees on 'Rusk' citrange survived the 1951 freeze in Texas (2), and only 33% survived the freezes in Louisiana. These data suggest that trees on 'Rusk' are relatively intolerant of cold. This is further supported by results in Florida, in which, after three consecutive freezes in a flatwoods planting of different scion-rootstock combinations, more trees on 'Rusk' needed to be replaced than trees on either 'Carrizo' or 'Troyer' (10). In Louisiana, trees on 'Rusk' were susceptible to freezing and flooding (Tables 2, 3). However,

Table 2. Survival of 5-year-old Owari satsuma trees on different rootstocks 30 days after a 20°F freeze (-6.7°C) in February, preceded by 14°F (-10°C) in December, near Port Sulphur, La.

Rootstocks (total of 12 ea)	Survival (%)
Trifoliate orange selections:	
Rich 22-2	100
English small	92
Towne F	92
English large	83
Rubidoux 56-6	83
Jacobson 56-5	75
Swingle	75
Kryder medium	75
Christiansen 56-4	67
Benecke 56-3	58
Yamaguchi 56-7	58
Argentina	58
Chambers small	58
Chambers large	42
Chambers large	42
Towne G	25
Citranges:	
Uvalde	75
Morton	50
Carrizo	50
Troyer	50
Rusk	33

Table 3. Percent survival of 3-year-old Washington navel orange trees on citrange rootstocks after a hurricane in Louisiana[z]

Rootstocks	No. of days rootstocks remained flooded		
	2-4[y]	10-12[x]	14-16[x]
(citrange)			
Troyer	87	33	0
Carrizo	80	67	0
Rusk	67	0	0
Uvalde	67	67	0

[z]Hurricane Betsy caused the Mississippi River to overflow its levee on September 9-10, 1965 and inundated the root systems of the trees.
[y]15 trees/rootstock.
[x] 6 trees/rootstock.

none of the citranges tolerated more than 2 weeks of continuous flooding under the test conditions. It is not known whether citranges are similar to *P. trifoliata,* which decreases in flooding tolerance as soil pH decreases (3, 4).

More than 50% of the unbudded plants of citradia and citrumelo 4475 survived three winters in Georgia (Table 1). Citradia as yet is largely an untried rootstock for citrus; whereas, citrumelo 4475 shows promise as a productive rootstock in Texas (9). Grapefruit trees on citrumelo 4475 showed excellent survival during the 1951 freeze in Texas (2). During the 1962 freeze in Texas, 4-year-old 'Redblush' grapefruit trees on citrumelo 4475 had more survivors than did trees on 'Cleopatra' mandarin and 'Shekwasha' mandarin (19). 'Cleopatra' and 'Shekwasha' showed poor survival relative to citrumelo 4475 in our test in Georgia (Table 1).

There are reports that weaken the implication that citrumelo improves freeze-tolerance in citrus trees more than 'Cleopatra' rootstocks. For example, equal numbers of 1-year-old grapefruit trees on 'Cleopatra' and citrumelo rootstocks survived the 1951 freeze in Texas (2). Also, cold injury ratings of budded trees, rather than numbers that survived freezes in Florida, place citrumelo 4475 slightly below 'Cleopatra' in cold tolerance (5); and citrumelo 4451 is equal to 'Shekwasha' mandarin (6). These reports from different areas tend to be somewhat conflicting. Inconsistencies are often attributed to differences in weather, soil, and plant material.

However, field tests supplemented with con-

Table 4. Injury to citrus rootstock selections exposed to controlled conditioning[z] and freezing[y]

Example	Selections	Treatment[x]	Foliage kill $\bar{X} \pm$ S.E.	Foliage kill Range	Stem dieback $\bar{X} \pm$ S.E.	Stem dieback Range
			(%)	(%)	(%)	(%)
1	Citradia	NC	67 ± 10	25–100	6 ± 3	0–43
		C-2	38 ± 12	0–100	< 1	0–5
	Citrandarin	NC	84 ± 10	10–100	30 ± 10	0–96
		C-2	25 ± 6	0–90	2 ± 1	0–8
	Citrangor	NC	87 ± 7	10–100	12 ± 4	0–60
		C-2	1 ± 0.3	0–5	< 1	0–2
	Citrangedin	NC	97 ± 2	80–100	20 ± 5	0–61
		C-2	32 ± 3	15–60	0	-
2	Cleo X Swingle	NC	100	-	75 ± 5	20–100
		C-2	1 ± 0.4	0–3	< 1	0–9
3	Cleo X Christiansen	NC	100	-	63 ± 3	43–87
		C-1	42 ± 6	-	12 ± 12	0–41
		C-2	25 ± 5	5–50	10 ± 3	0–35
	Cleo X Rubidoux	NC	100	-	67 ± 5	39–100
		C-1	60 ± 10	5–100	4 ± 1	0–11
		C-2	43 ± 7	10–90	2 ± 1	0–10
	Cleo X Troyer	NC	100	-	89 ± 2	66–100
		C-1	100	-	63 ± 5	31–95
		C-2	40 ± 9	10–100	14 ± 3	0–35

[z]NC = not conditioned (glasshouse)
C-1 = 70° F (21.1° C) days and 50° F (10° C) nights for 2 weeks.
C-2 = C-1 followed by 2 weeks of 60° F (15.6° C) days and 40° F (4.4° C) nights.
[y]20° F (-6.7° C) for 4 hours.
[x]Total of 12 plants/treatment.

trolled-environment tests may assist in rapidly classifying and identifying potentially good breeding material. In our controlled environment studies using unbudded plants, we can readily establish the relative low tolerance of 'Rough' lemon (*C. limon* [L.] Burm. f.) to freezes, the intermediate tolerance of sour orange (*C. aurantium*), and the high tolerance of trifoliata orange. Other examples of our controlled tests show that the extent of hardening off is similar in citradia, citrandarin, citangedin, and citrangor (Table 4). Citradia and citrangor selections were uninjured by 12°F (-11.1°C) in Texas in 1962 (12). A hybrid of 'Cleopatra' mandarin X 'Swingle' trifoliate orange hardens off adequately in our controlled tests; although 'Cleopatra' did not survive in Georgia and showed variable performance in Texas and Florida. The other parent, 'Swingle', showed a high percentage survival with satsuma trees after freezes in Louisiana (Table 2). 'Cleopatra' X 'Christiansen' trifoliate or 'Rubidoux' trifoliate hardened off more than 'Cleopatra' X 'Troyer' citrange in controlled tests; whereas trees on 'Christiansen' and 'Rubidoux' survived better than trees on 'Troyer' during freezes in Louisiana (Table 4).

The relative differences among 'Christiansen', 'Rubidoux', and 'Troyer' rootstocks, shortly after adverse conditions in Louisiana, still were apparent 7 years later. Sixty-seven percent of the trees on 'Rubidoux' survived, and more trees on 'Christiansen' survived than on 'Troyer' (Table 5). Both 'Christiansen' and 'English small' were high in overall survival and yields of fruit after freezes

Table 5. Association of *P. trifoliata* selections and citrus rootstocks with the survival and fruit yield of Owari satsuma trees exposed to freezing and flooding in Louisiana during 1964 and 1965

Rootstock	Survivors in 1972	Lb. fruit/tree (1967-1972)			Variation in yield
		Highest	Lowest	5 yr avg	
	(%)				(%)
Trifoliata					
Rubidoux 56-6	67	222	114	166	67
English small	60	234	186	212	10
Christiansen 56-4	50	249	206	230	8
Towne F	50	268	150	206	30
Rich 22-2	50	229	155	190	20
Jacobson 56-5	50	218	144	184	19
Swingle	50	201	118	165	22
Yamaguchi 56-7	42	276	147	221	25
Benecke 56-3	42	240	151	205	17
Kryder medium	42	235	114	173	35
Argentina	33	317	198	235	35
English large	33	206	136	176	17
Chambers large	33	206	109	144	43
Chambers small	17	273	259	266	-
Towne G	0	-	-	-	-
Citrange					
Troyer	33	204	135	174	17
Carrizo	25	255	180	228	12
Morton	25	210	180	192	10
Uvalde	25	168	141	153	10
Rusk	17	160	98	129	17

and flooding in Louisiana. The poorest trifoliate orange selection was 'Towne G'; 'Rusk' was the poorest of the citranges and is reported by others to be poorer than 'Morton', 'Carrizo', and 'Troyer' in fruit yield from undamaged 'Valencia' trees in Florida (7).

Our field observations in Louisiana and Georgia, plus our controlled-environment tests, show that 9 of the 30 selections tested have merit for further study in increasing the tolerance of citrus trees to freezes and flooding. These rootstocks include 7 selections of trifoliate orange, a citradia and citrumelo 4475. Trifoliate selections include 'Rubidoux 56-6', 'Christiansen 56-4', 'English small', 'Rich 22-2', 'Towne F', Jacobson 56-5', and 'Swingle'. 'Rusk' was less desirable than 'Carrizo', 'Uvalde', 'Morton', or 'Troyer' citranges.

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INSTRUMENTATION METHODS AND PHOTOGRAPHIC TECHNIQUES FOR DETECTION OF CITRUS TREES AFFECTED WITH YOUNG TREE DECLINE

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Abstract. **Studies have been started to develop an instrumentation method and/or a remote sensing technique for detection and diagnosis of citrus trees affected by Young Tree Decline (YTD). The temperature of severely diseased trees was found to be warmer than either healthy trees or the ambient air temperature when measured with a remote sensing portable infrared thermometer; but there was virtually no difference between the temperatures of healthy trees and trees in slight and moderate decline. A temperature difference across the bud union between stock and scion was detected with a platinum resistor sensor. This temperature differential was greater in diseased trees than healthy trees and the difference increased with severity of disease. With a Sholander pressure bomb, 1.5 to 2.0 times more pressure was required to force liquid out of leaves from diseased trees than from leaves of healthy trees. The electric potential across the bud union changed from positive in healthy trees to negative in diseased trees. Infrared photography was useful only as a means of demonstrating the more severely diseased trees, but has not been fully tested. Although differences between healthy and diseased trees were detected with instruments, these physi-**

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